# APPENDIX G

# CPM NETWORK

## G-1. USING CPM

The first step in using CPM is to determine the tasks required to complete the project as outlined in the directive. The next step is to ask the three following questions about each task:

*a. Precedence.* What tasks must be finished before this task begins?

*b. Concurrence.* What tasks may either start or finish at the same time that this task does?

*c. Succession.* What tasks cannot begin until this task is finished?

## G-2. CPM SYMBOLS

*a. Activity Arrows and Event Nodes.*

*(1) Arrows.* An arrow represents each activity (that is, any time-consuming part of the project); the arrow's tail and head represent an activity's start and finish, respectively. An arrow's length or angular direction is not related to how much time the activity takes; that is, the arrow is not time scaled. The way that the arrows are interconnected indicates which activity precedes or follows another.

*(2) Event Nodes.* A circle, which is called an event node, represents the start or finish of an activity. Numbers in the event node identify activities in the diagram. The rule for numbering events is that the number at the head of the arrow must be larger than the number at the tail. (For digital computer use, the arrow's tail could be designated "i" and its head "j." Each activity is then assigned a unique i-j designation.) In figure G-1, the activity may be called either "pour concrete" or "activity 5-8."

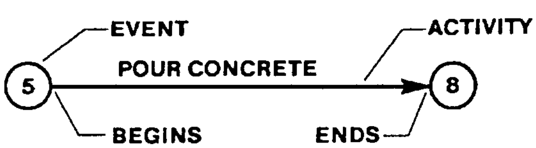


*Figure G-1. Event numbers*

*b. "I-J" Numbering.* The i-j numbering convention can eliminate certain problems in CPM construction, such as a circular logic error. Figure G-2 shows a typical circular logic error. The number of the event at the head of activity G must be greater than 15; however, the number at the tail of activity H must be less that 10. Since the event numbering rule cannot be followed here, the i-j convention would prevent the error.

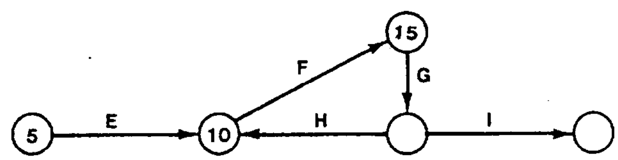


*Figure G-2. Circular logic error*

*c. CPM Logic.* The logic behind CPM networks is that an activity (arrow) leaving an event (circle) cannot begin until all activities heading into that event are completed. Figure G-3 shows that activity B cannot begin until activity A is completed. It also indicates that activity G cannot start until activities C and D are finished and that neither activity D nor H can start until activity I is completed. Activities C and D are concurrent because they can end at the same event, and activities D and H can start at the same time.

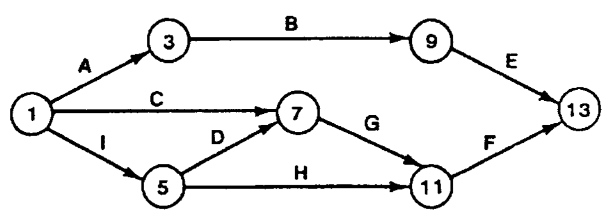


*Figure G-3. CPM network*

*d. "Dummy" Arrow.*

*(1)* A "dummy" arrow is another CPM device that shows a sequence relationship but does not represent any activity. A brief example can demonstrate the use of the dummy arrow: Suppose that an engineer unit is to

construct a gravel road and pour concrete nearby. Assume that the same gravel and rock should be used for both the road surface and the concrete. The CPM diagram might look like figure G-4.

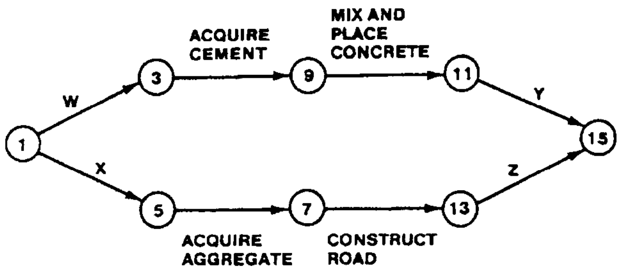


*Figure G-4. Example CPM diagram*

*(2)* As shown in figure G-4, the road depends on having the aggregate, and the concrete mixing depends on having the cement; however, mixing the concrete also requires having the aggregate. Therefore, the concrete depends on both the cement and the aggregate. The figure also shows that constructing the road depends on acquiring the cement, even though cement is not required for its construction. According to the diagram, road construction would be constrained unnecessarily.

*(3)* The way out of the problem is to draw a dashed arrow from the end of the aggregate activity to the beginning of the concrete activity. The dashed arrow simply shows a sequence relationship (concrete depends on aggregate) that has no name and does not represent any part of the project. Thus, the dashed arrow is called a "dummy" activity, as shown in figure G-5.

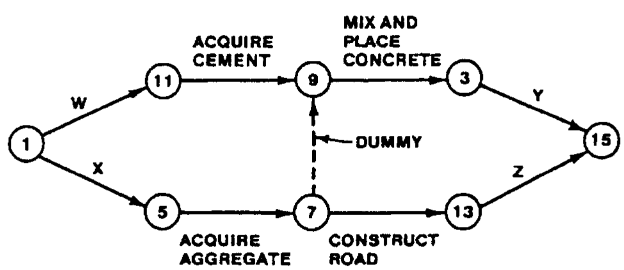


*Figure G-5. "Dummy" activity*

*e. Event Times.* The next step in the CPM process is to calculate the earliest and latest times when events can occur. An event occurs immediately after all activities going into it are completed; thus, succeeding activities cannot start until the event has occurred. Event times represent the end of the time period needed to complete an activity; therefore, an event time of 5 would mean the end of the fifth day (or hour, week, etc.). Several definitions related to various event times used in the CPM process are listed in paragraphs *(1)* through *(8)* below:

*(1) Duration (D).* The shortest time, expressed in any desired unit, required to perform an activity.

*(2) Earliest Start (ES).* The earliest time that an activity can be started.

*(3) Earliest Finish (EF).* The earliest time an activity can be finished:

$$EF = ES + D$$

*(4) Latest Start (LS).* The latest time an activity can be started without delaying completion of the project:

$$LS = LF - D$$

*(5) Latest finish (LF).* The latest time that an activity can be finished without delaying completion of the project:

$$LF = LS + D$$

*(6) Total Float (TF).* The amount of time that the start or finish of any given activity can be delayed without delaying completion of the project:

$$TF = LF - EF \text{ or } LS - ES$$

*(7) Free Float (FF).* The amount of time that the finishing of an activity can be delayed without delaying the earliest starting time for a subsequent activity:

$$FF = ES \text{ (following activity) } - EF \text{ (of this activity).}$$

*(8) Critical Path.* The critical path is the series of interconnected activities through the network in which each activity has zero float time. The critical path determines the minimum time required to complete a project.

*f. Computer Generated CPM.* A computer program that uses the CPM technique to facilitate rapid scheduling of AFCS military construction projects in the TO has been developed. The program computes the most qualified engineer construction unit(s) and the number of work days needed for construction.

*Table G-1. Construction activities for CPM example*

| ACTIVITY | DESCRIPTION |
|---|---|
| Site preparation | Clear site, compact subbase, and lay out building and parking area. |
| Install forms | Excavate footings; install reinforcing and forms. |
| Under-slab utilities | Install electrical conduit and water, gas, and sewer pipes. |
| Place concrete | Place, finish, and cure concrete slab; remove forms. |
| Place concrete block | Place concrete block walls, reinforcing bars, anchor bolts, and grout. |
| Install trusses | Install top plate, erect trusses, block, and brace. |
| Precut frame walls | Cut plates, studs, trimmers, headers, and stock on site. |
| Frame | Frame interior walls in place. |
| Roofing | Install plywood decking, roof gutters, downspouts, and asphalt shingles. |
| Utilities | Install electrical conduit, wiring, plumbing pipes, and heating ducts. |
| Finish interior | Install doors, windows, shelves, trim, counter, flooring, lights, outlets, switches, latrine fixtures, heater and hot water tank, wallboard, and paint. |
| Walk and steps | Lay out, form, brace, place concrete, finish concrete, and remove forms. |
| Parking area | Install culvert, place base course, and pave. |

## G-3. CPM EXAMPLE

*a. Problem Description.* The following CPM example considers the construction of a typical TO building: A 20-foot by 40-foot office building is to be constructed in an ammunition storage area. It will use concrete block with slab-on-grade wood-frame wall partitions and wood roof trusses. A breakdown of the construction activities is listed in table G-1.

*b. Determining Activity Duration.* After the construction activities have been determined for the CPM diagram, each activity's duration must be determined. Activity duration (in terms of days) is a function of the engineer unit work capability to be employed and the size of the jobs to be done. TM 5-301 lists the total man-hours required for a particular job. To determine durations, refer to the TOE and apply experience gained from previous construction. The three questions concerning precedence, concurrence, and succession for each activity are then asked (see pargraph G-1). The results have been used to construct the CPM diagram (figure G-6). The numerals below the activities are the durations (in days) allotted for completing those activities.

*c. Early Event Time (EET).* Also shown on the CPM diagram (in the square above each event number) are the early event times. They are used to determine the earliest time that each event in the path can be started. The early event time equals the longest of the paths coming into an event. Figure G-6 shows that the project will take an estimated 27 working days, or about 4 weeks.

*d. Late Event Time (LET).* The late event times are placed below each event number in the triangles. The late event time is the latest time that an event can occur and not delay the project beyond the earliest completion time; therefore, the late event time and the early event time for the ending event are the same. To find the other late event times, work backwards through the diagram against the arrows, subtracting activity durations from the late event time at the head of an arrow to get the late event time at the tail of the arrow (disregarding the early event times.) Where there is a choice of late event times,

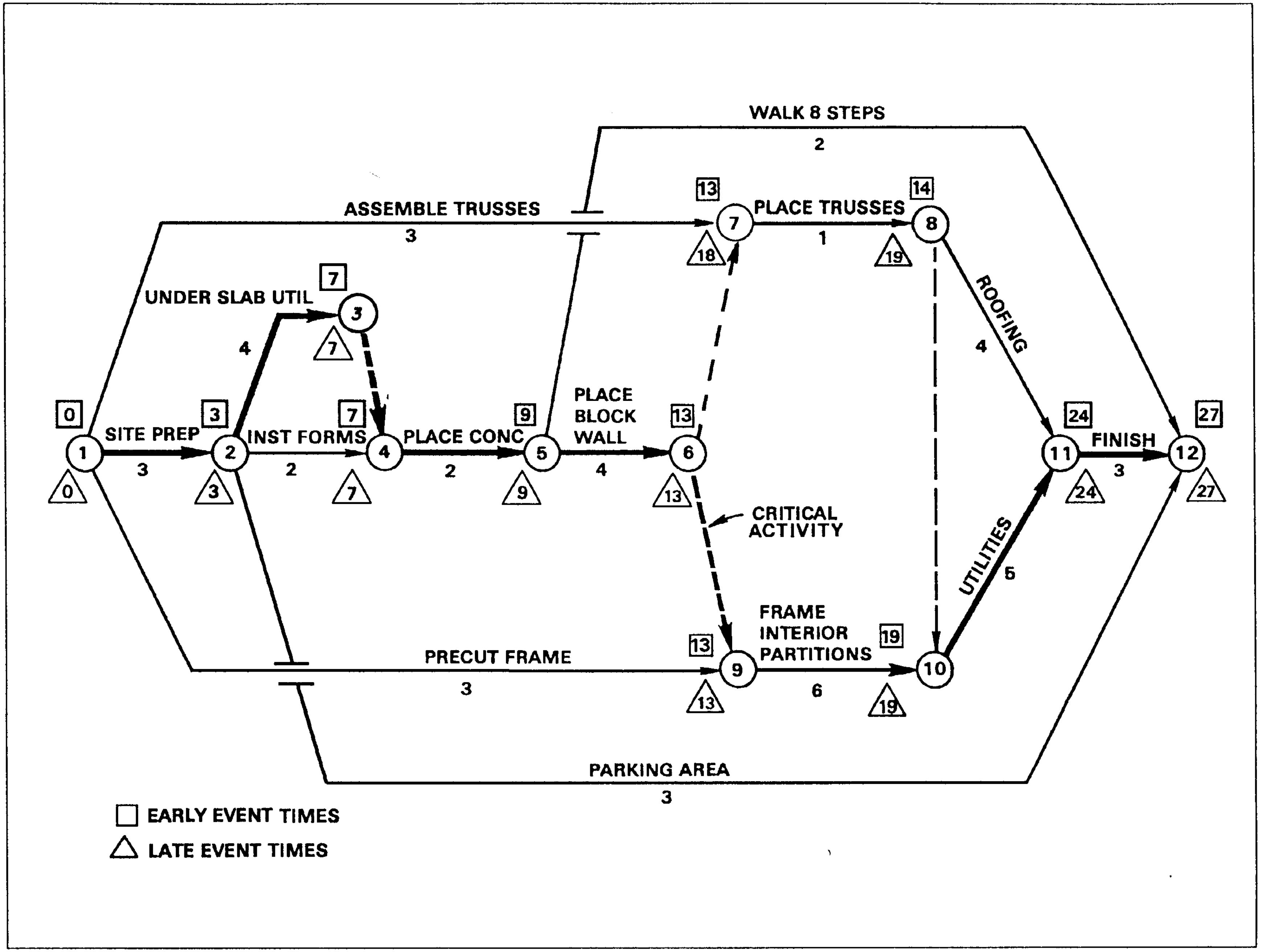


*Figure G-6. CPM diagram for a typical office building*

*Table G-2. Tabulation of construction activities*

| Activity | Title | D | ES | EF | LS | LF | TF |
|---|---|---|---|---|---|---|---|
| 1-2 | Site preparation | 3 | 0 | 3 | 0 | 3 | 0 |
| 1-7 | Assemble trusses | 3 | 0 | 3 | 15 | 18 | 15 |
| 1-9 | Precut frame walls | 3 | 0 | 3 | 10 | 13 | 10 |
| 2-3 | Under-slab utilities | 4 | 3 | 7 | 3 | 7 | 0 |
| 2-4 | Install forms | 2 | 3 | 5 | 5 | 7 | 2 |
| 2-12 | Parking area | 3 | 3 | 6 | 24 | 27 | 21 |
| 4-5 | Place concrete | 2 | 7 | 9 | 7 | 9 | 0 |
| 5-6 | Place concrete block | 4 | 9 | 13 | 9 | 13 | 0 |
| 5-12 | Walk and steps | 2 | 9 | 11 | 25 | 27 | 16 |
| 7-8 | Install trusses | 1 | 13 | 14 | 18 | 19 | 5 |
| 8-11 | Roofing | 4 | 14 | 18 | 20 | 24 | 6 |
| 9-10 | Frame walls | 6 | 13 | 19 | 13 | 19 | 0 |
| 10-11 | Utilities | 5 | 19 | 24 | 19 | 24 | 0 |
| 11-12 | Finish | 3 | 24 | 27 | 24 | 27 | 0 |

choosing the smallest one will ensure that the project is not delayed. If the last late event time calculated is not zero, a mistake has been made. (See figure G-6.)

*e. Critical Activity.* A critical activity is an activity which if delayed would delay the entire project. In a critical activity, the earliest and latest event times at the tail of the arrow are equal, and the earliest and latest event times at the head of the arrow are equal. For activities that pass those criteria, the EET (or LET) at the head minus the EET (or LET) at the tail is equal to the duration of the activity:

$$D = EET_{head} - EET_{tail} \text{ or } D = LET_{head} - LET_{tail}$$

*f. Tabulation of Construction Activities.* Perhaps the easiest way to get information from the CPM diagram is to construct a table that shows the activity number and title, activity duration, earliest start, and latest finish. (See table G-2.) Adding duration to the ES column and subtracting it from the LF column yields EF and LS, respectively. TF then is simply LS minus ES (or LF minus EF). All activities with zero TF are on the critical path. In table G-2, an ES of 0 means that work starts at the beginning of time period 1, and an LF of 3 means work ends at the end of time period 3. As shown in figure G-6, the shortest time in which the project can be completed is 27 days (see column EF of activity 11-12).